EMPIR Call 2019 – Energy, Environment, Normative and Research Potential

Selected Research Topic number: **SRT-g03**
Version: 1.0

Title: Metrology of magnetic losses in electrical steel sheets for high-efficiency energy conversion

Abstract

Magnetic steel sheets are the core of electric motors, generators, and transformers, which produce and convert virtually all the energy from conventional and renewable sources. Steel producers strive to develop thinner and highly energy-efficient grain-oriented (GO) and non-oriented (NO) magnetic steels, with enhanced permeability, apt for kHz frequencies. Novel products require magnetic loss measurements close to saturation induction, at high frequencies, and with low uncertainty. In order to address these industrial and end-user needs, traceable magnetic measurements up to 10 kHz and above 1.8 T need to be developed and validated. This will lead to improved metrological procedures for magnetic loss measurements with outcomes expected to be used in the power generation and supply industry, the transport sector and in the machinery and metal products industries, leading to an increased energy conversion efficiency.

Keywords

Motor efficiency, Transformer efficiency, Magnetic loss, Transformer loss, eddy current loss, Hysteresis, Magnetic Steel, Grain Oriented Magnetic laminations, Non Oriented Magnetic Laminations

Background to the Metrological Challenges

Magnetic steel is used for two main applications: electric motors/generators and transformers. In both cases the energy losses occurring in the cyclic magnetising of the material are very significant. Even a small improvement in the reduction of magnetic losses has a significant impact on the life cost of any electric motor or transformer.

The measurement of magnetic losses in steel sheets is regulated, at the international level, by the Standards IEC-60404-2 and IEC-60404-3, dealing with the Epstein frame and Single Sheet Test methods (SST), respectively. The old standard IEC-60404-10 contemplates the use of the Epstein test frame in the frequency range 400 Hz-10 kHz. A number of intercomparison studies have confirmed, for both Epstein and SST methods, a good reproducibility, with an uncertainty of around 1 % for the power loss and of slightly more than 2 % for the apparent power. Remarkably, neither testing method provides the true value of the power loss.

At present all magnetic loss calibration measurements at European NMIs are only carried out at room temperature. However, measurements at operating temperatures exceeding 100 °C, where saturation magnetisation, anisotropy and electrical conductivity are reduced (with a direct impact on the skin effect and loss), are required to evaluate the energy losses of electrical machines under practical operation conditions.

In addition to eddy currents, the physical origin of magnetic losses is based in the magnetic domain structure on the micrometre scale and at the nanometre scale. Modern surface analysis tools can help to improve the understanding of the magnetisation process and associated energy losses both at elevated temperatures and after mechanical damage due to cutting, punching, and surface scribing. However, no systematic metrological investigations are available linking the magnetic micro- and defect-structure to standardised measurements.

Although no comparisons have been so far carried out and published at frequencies differing from 50 Hz, present-day electrical machine cores (e.g. high-speed motors) can easily operate in the kHz range. With electronically driven brushless motors, the flux derivative in the core is endowed with a substantial harmonic content and the magnetic losses are accordingly increased. Only a few laboratories can accurately test the materials properties under this type of supply.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable magnetic loss measurements in electrical steel sheets.

The specific objectives are

1. To build and validate an improved metrological infrastructure for the determination of power losses with relative standard deviation down to 1 %, using Single Sheet and Epstein frame magnetic circuits in electrical steel laminations at induction values close to saturation and at frequencies ranging from DC to 10 kHz with flux waveforms of different harmonic content. The dynamic magnetic characterisation will target novel thin laminations with thickness as low as 0.10 mm for non-oriented steels and 0.18 mm for grain-oriented materials.
2. To build and validate a new metrological infrastructure for Epstein frame measurements at temperature values up to 155 °C, corresponding to the “F class” insulation (IEC-60085 and IEC-60034-1), to match the typical operating temperatures of electric motors, with a direct impact on loss and efficiency evaluation, since the current standard measurement temperature is 23 °C ± 5 °C.
3. To study and model power losses in thin sheets upon a DC-MHz frequency regime, with the help of fluxmetric, magneto-optical characterisation techniques as well as scanning probe techniques for the sub-µm regime.
4. To use one dimensional and two-dimensional measurements and physical models, taking into account the non-uniform flux profiles due to the skin effect in order to breach the gap between standard loss characterisation under ideal conditions and real operating condition of state of the art magnetic devices. To also emulate the two-dimensional flux loci in the non-oriented steel laminations in the stator core of a rotating machine.
5. To facilitate take up of results by industry, NMIs and standardisation bodies (IEC TC-68 and ISO) by providing guidelines for improved traceable magnetic loss measurements at higher frequency and induction, allowing for an evolution of the current IEC 60404 standards for loss measurement reflecting up-to-date industrial needs.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.0 M€, and has defined an upper limit of 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the power generation and supply industry, transport sector and the machinery and metal products industries sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.